Thesis
S497

An Oscilloscope Sweep Circuit Providing Timing Markers and a Method of Measuring Signal Amplitude

By

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and

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The authors are greatly indebted to Mr. R.L. Snyder, Jr. for suggesting this topic and for his suggestions of possible methods of its solution.

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Section I

Introduction to the Problem

The problem, as suggested by Mr. R.L. Snyder, was to design a sweep system for an oscilloscope which would sequentially present on the trace three signals. The first would be the trace of the input signal, the second would be a horizontal line representing a voltage level with superimposed timing markers, the third would be another horizontal line representing a lower voltage level than the first. The relative amplitudes of the first trace with respect to the difference of the other two should be variable and calibrated to allow direct indication of the amplitude of the input signal. After some discussion it was decided that it would be desirable to meet the following specifications if possible:

Sweep:

Push-pull, peak to peak voltage, 250 volts.

Speed, variable in steps from one microsecond to .01 seconds.

Driven sweep only provided.

Return trace to be blanked during the flyback period.

Both internal and external synchronization to be provided.

Signal:

Overall signal circuit band width as near ten megacycles as possible.

Output signal amplitude variable to a maximum of 150 volts, peak to peak.

Input attenuator calibrated directly in terms of signal voltage amplitude.

Suitable signal delay to be provided so that the sweep will start before the signal starts.

Timing Markers:

To be provided on the upper of the two voltage traces only.

Ten marks per sweep to be provided except on the one micro-second sweep. On this sweep marks provided at .4 micro-second intervals.

Presentation:

The trace may be presented on any oscilloscope on which connection may be made directly to the deflection plates and the intensity grid.

Due to the late start on this project and the press of other work, the complete circuit has not been constructed. However, we believe that sufficient construction and testing has been done to demonstrate the practicability of the designs evolved.

Section 2

The Overall Circuit

The overall block diagram is shown in Plate I. The overall operation of the instrument will now be described, and the individual sections will be analyzed in greater detail later.

The incoming signal is fed into a conventional cathode follower circuit and from there goes through the input gating tube, the 1N34 clamper circuit (which has no effect on the signal), a conventional voltage amplifier, and finally through the delay line and power amplifier section to the Y deflection plates.

Reference to Plate I shows that at the beginning of the delay line the signal is also sent through a two way switch, then through an "and" gate followed by an "or" gate, to a 6J6 inverter. The negative signal from the 6J6 inverter is fed to the flip-flop and also to the 6J6 charging tube. The flip-flop reinforces this negative signal if set and simply lets it go through it reset. The negative signal from the flip-flop then performs the following operation:

It cuts off the sweep charging tube (6J6) and allows the discharge circuit to initiate the sweep through the sweep amplifier to the X plates. A part of this sweep is sent back through a 6AG5 pulse former to appear at the flip-flop as a negative signal to set the flip-flop, and thus give out a positive kick from the flip-flop to turn the charging tube back on and to operate the unblanking circuit to blank the return trace.

A positive pulse is supplied by the flip-flop to the binary counters. Assuming them both set in the 0 position originally, this positive pulse will cause both binary counters to operate and shift to the 1 position. In the case of counter #1, this energizes "and" gates #2 and #4.

"and" gate #4 also receives a pulse from counter #2 and hence transmits a positive pulse to the switching tubes which effectively slams the Y deflection plate against one of the 1N34 clampers.

"and" gate #2 also receives a pulse from the "pulse generator" and transmits this positive pulse through the "or" gate and hence initiates another sweep, this time at a fixed predetermined value away from the center position of the sweep.

Counter #2, of course, operates at ½ the count of counter #1, and hence the fixed predetermined values of Y deflection are swept through only every other sweep. Thus the cycle of operation proceeds as follows:

a) Signal appears normally.

b) Fixed sweep across at a predetermined level above the center position.

c) Signal appears normally.

d) Fixed sweep across at a predetermined level below the center position.

The input circuit must be calibrated so that the attenuation necessary to place the signal between the two fixed sweeps is accurately known, and hence the peak value of the signal is read directly. This is best done experimentally.

Separate synchronization of the sweep can come through the other section of the two way switch in order to operate the instrument as a conventional oscillioscope.

Section 3

The Input Circuit

The input circuit includes the input and voltage amplifier tubes up to the delay line, and also includes the devices used for clamping the Y plate trace to a predetermined value. The input circuit is shown on Plate II.

The signal is fed into a 6C4 cathode follower through a .5uf. oil filled condenser and across 1 megohm to ground. The cathode resistor of the 6C4 is a 1K carbon potentiometer which must be finally calibrated after the unit is constructed to read directly the peak to peak value of the signal. For the 6C4 under the conditions shown:

$\mu = 17$

$r_p = 7700\,\Omega$

$R_L = \frac{1000 \times 5100}{6100} = 835\,\Omega$

The gain of the cathode follower is:

$$K = \frac{\mu}{\mu+1}\,\frac{R_L}{R_L + \left(\frac{r_p}{1+\mu}\right)} = \frac{17}{18}\,\frac{835}{1263} = .623$$

The input resistance is:

$$\frac{R_c}{1-K} = 2.65 \text{ megohm}$$

From the cathode follower input, the signal is fed to a 6AK5 amplifier. The cathode of this tube is connected to the mid-point between the two 6AQ5 tubes in series, the purpose of which will be described shortly. The whole tube, including plate and cathode load resistors, is across -200 volts and the plate load resistor is grounded. This places the plate at about -4 volts with respect to ground and gives a gm of 5000. The gain of this stage is 10.

The signal then proceeds to the 6AC7 voltage amplifier which has a gain of about 12. This gives a total voltage amplification of 10 x 12 x .625 = 75.

The clamping circuit consists of two 6AQ5 tubes with associated 6C4 actuating tubes, and two 1N34 crystals with power supplies or batteries. It is seen from Plate II that the two 6AQ5 tubes are between -100 and -300 volts, so that their mid-point is at approximately -200 volts and is at the same potential as the cathode of the 6AK5. The two 1N34 crystals are placed between the plate of the 6AK5 and two power supplies or batteries, one of which is at -2 volts and the other at -6 volts. Thus if the plate of the 6AK5 swings past -2 or -6 volts it will be effectively clamped at this point by the 1N34 crystals.

In practice the action of the clamping is as follows:

The 6C4 tubes are normally biased to cut off and if no pulses appear from gates #3 and #4, the current flowing through the upper 6AQ5 goes through the lower 6AQ5 and the input circuit is undisturbed. Now, suppose a positive pulse appears from gate #3. The upper 6AQ5 will be shut off and the plate current of the 6AK5 will flow through the lower 6AQ5, thus lowering the bias of the 6AK5 and increasing its plate current. This drags the plate below -6 volts, where it clamps until the pulse from gate #3 is gone. If, on the other hand, the pulse appears from gate #4, the lower 6AQ5 is cut off and the plate current from the upper 6AQ5 then flows through the cathode resistor of the 6AK5, increasing its bias and cutting it off. This drives the plate of the 6AK5 up toward ground, but it clamps at -2 volts due to the 1N34 crystal.

To sum up, a signal at the input will be undisturbed if no pulse appears from gate #3 or gate #4. A pulse appearing at gate #3 will cause the plate of the 6AK5 to clamp at -5 volts. If it appears from gate #4, the plate will clamp at -2 volts.

The transformers shown in the 1N34 circuit are for the purpose of introducing markers. They are 30 to 1 ratio transformers. The markers appear at a 2.5 megacycle rate and are introduced into this circuit and appear on the Y deflection plates as pips .25 u sec apart.

Section 4

The Switching Circuits

The switching circuits include gates #1, #2, #3, #4, #5, counter #1, counter #2 and the flip-flop. They will be discussed in that order.

Gates #1, #2, #3 and #4 are "and" gates, so called because it requires a pulse at both inputs simultaneously to transmit one pulse through the gate. Referring to Plate III c, it is seen that the "and" gate consists of 3 diode sections. The input pulses cut off one diode each, but unless both diodes are cut off simultaneously, no pulse is transmitted. The third diode acts as a limiter on negative tails, etc.

The "or" gate, which is gate #5, operates in a similar fashion, except that any positive pulse appearing at either input increases the flow of current through the common cathode resistor and thus transmits a positive pulse on. The "or" gate is shown on Plate III c.

There are two binary counters in series as show on Plate III a. The 0 position is with the left tube conducting. When a positive pulse appears at the grid of the initial 6J6, a large negative pulse appears at the plates and hence at the grids of both counter tubes. This causes the tubes to switch and counting takes place. As a positive pulse only comes out of counter #1 every other count, counter #2 runs at ½ the speed of counter #1. This counter circuit was checked and found to be operating satisfactorily, using initial pulses of .4us. at a frequency of 100 K.

The flip-flop shown on Plate III operates the same as a single counter except that the initiating 6J6 has its own plate load and the flip-flop uses 6AK5 pentodes instead of 6J6's. The use of pentodes results in a more uniform and more rapid pulse than can be obtained by use of triodes. This circuit was also checked, using a pulse length of .4us. and a repetition frequency of 100 K.

Section 5

The Marker Circuits

The circuit details of the marker generator are shown in Plate IV. Its operation is as follows. The system consists of five parts: a 6SJ7 transitron sine wave oscillator, a 6AC7 voltage amplifier, a 6AQ5 power amplifier, a 6AQ5 clamper, and an R-C differentiating circuit.

The 6SJ7 oscillator is a simple negative resistance oscillator and was selected because of its high stability and because it required only a simple parallel tank circuit. This is important because it simplifies the problem of switching tank circuits and this oscillator must cover a range of 1000 c.p.s. to 2.5 m.c.s. The frequency stability of this circuit must be very good as this frequency determines the accuracy of the timing markers. It was tested and calibrated, using Lissajou figures on an oscilloscope, against a Measurements Corporation, type 65-B, R.F. Signal Generator. The stability of this oscillator is as good as that of the Measurements signal generator (i.e. better than 0.1 % accuracy). The grid cathode potentiometer setting for the 6SJ7 indicated in Plate IV is not critical and after a good value is determined, the potentiometer may be replaced by two fixed carbon resistors.

The output of the oscillator drives a 6AC7 voltage amplifier. The plate load of this amplifier is compensated with a series choke which should resonate the plate to ground capacity at a frequency of 2.5 m.c.s. The plate load resistor is chosen to give this circuit a "Q" of unity. This gives a gain characteristic which increases slowly with frequency throughout the range in which this amplifier is used. This rising characteristic compensates for the tendency of the oscillator and power amplifier to drop off at the high frequency end of the band and maintains the amplitude of the marker spikes approximately constant over the range of frequencies desired.

The output of the voltage amplifier drives a 6AQ5 power amplifier which slightly clips both the top and bottom peaks of the sine wave input. The output of the power amplifier is clipped by two halves of a 6AL5 as indicated, yielding a reasonably square wave. The amplitude of the square wave is twenty volts, peak to peak.

This square wave goes into a differentiating circuit which puts out a series of alternate positive and negative spikes. Only the negative spikes are used as timing markers as has already been explained in Section 3. Thus the marker frequency is the same as the oscillator frequency since one marker is produced per cycle.

Section 6

The External Synchronizing Circuit

The circuit details of the external sync amplifier are shown in Plate V. It consists of two 6AC7 voltage amplifiers.

This circuit serves only one purpose. It would be useful if it were desired to measure the delay of a signal in one circuit with respect to another one. This could be done by setting the switch for external sync and synchronizing the sweep with the earlier of the two signals. Then feed the first signal into the input circuit and note the point on the trace where a recognizable part of the signal occurs. Now feed the second signal into the input circuit and note where the same part of the signal now appears on the trace. The time difference between the two points will be the delay of one signal relative to the other.

The circuit is quite simple and consists of two cascaded 6AC7 amplifiers which amplify and clip any input signal to give a pulse or square wave with a reasonably good rise time to feed through the switching circuits and trigger the sweep. No particular remarks are needed on these circuits, as they are quite similar to some already discussed.

It should be noted, however, that driving the external sync source from the same signal driving the input circuit will have the effect of presenting a lower input impedance to the signal source than would be the case if internal sync were used.

Section 7

The X-axis Sweep Generator

The circuit details of the sweep generator are shown on plate VI. Its operation is as follows.

The sweep generator proper consists of two halves of a 6J6, tied in parallel, in series with a 6AG5. Positive and negative pulses from the flip-flop in the switching circuit drive the grids of the 6J6 to zero bias or to cut off. When the 6J6 is cut off the sweep condenser "C" discharges through the 6AG5. This is practically a constant current discharge in the range of plate voltage of interest here, namely from 300 to 100 volts. The 6AG5 tube was chosen because its plate current variation in this range is extremely small if the screen supply is held constant. The screen voltage for all tubes in the chassis using 150 volts, should be taken from a separate regulated supply.

Since condenser "C" discharges at constant current, its voltage to ground varies at a constant rate in this interval. It is this voltage that is used to generate the x-axis sweep. This voltage is used to drive a 6AG7 phase splitter to generate the push-pull sweep to be applied to the x-plates of the oscilloscope. This circuit will furnish a 200 volt sweep.

Two adjustments of the sweep speed, coarse and fine, are provided. The coarse adjustment is the variation by switching of the value of "C". The fine adjustment consists of returning the grid of the 6AG5 to the movable contact of the potentiometer which forms the cathode resistor of the 6AG5. Varying the position of this center tap varies the bias and hence the plate current of the 6AG5, thus giving a fine control on the rate of discharge of "C".

Let us now return to the grid of the 6J6 and consider the other half of the sweep cycle. When the negative pulse from the flip-flop ends, the bias on the 6J6 returns to zero, and it begins conducting heavily, approximately seventy milliamperes for two units in parallel. Of this current, about ten mils flows through the 6AG5 and the remainder flows into "C", charging it again. "C" continues to charge until its voltage reaches about 330 volts or until another negative pulse from the flip-flop starts another sweep. In practice it was found that for a five u-second sweep the recharge time was about 40% of the sweep time if maximum sweep voltage was to be obtained. From this it is obvious that the flyback time of the sweep would be excessive. Therefore provision is made for blanking the screen during the flyback period.

The intensity of the oscilloscope being used is adjusted so that no trace appears on the screen. A square wave from the unblanking amplifier is applied to the intensity grid of the tube of the oscilloscope. The positive half of the square wave raises the voltage of the grid to a value such that the trace may be seen. The negative portion of the wave blanks out the trace. This amplifier consists of a single 6AG7 biased to zero. It is driven by the negative pulse from the flip-flop which triggers the 6J6 to start the sweep. Thus as the sweep starts the trace is unblanked and when the positive pulse from the flip-flop starts the flyback, the trace is blanked. A potentiometer input to the 6AC7 is provided to allow adjustment of the trace brilliance in the sweep system if it is not desirable to vary the intensity setting on the oscilloscope. This potentiometer also introduces enough resistance in series with the grid of the 6AC7 to keep it from driving very far positive and burning out the tube.

In addition to the circuits thus far discussed, the sweep generator includes a pulse forming circuit whose output is used to reset the flip-flop and initiate the flyback portion of the sweep cycle. This circuit consists of a single 6AG5 whose grid is driven by the positive half of the push-pull sweep. The cathode of this tube is grounded and its grid goes to a negative bias voltage of seventy-five volts through a ten megohm variable resistor. Adjustment of this resistor allows one to control the sweep voltage reached before the recharging half of the sweep cycle is initiated. The same result could be obtained by using a fixed resistor and varying the grid bias voltage, but this would be a more complicated method of accomplishing it. The 6AG5 is, of course, cut off and remains cut off until the portion of the sweep voltage appearing on its grid reaches seventy volts. At this point, the tube begins conducting and puts out a sharp negative pulse. This negative pulse is used to reset the flip-flop and initiates the flyback.

The values of the sweep condenser "C" for sweeps of various lengths are easily determined. As a preliminary step, it is desirable to determine the interstage capacity to ground of the circuit containing "C". This can be estimated to good accuracy by observing the sweep on a Dumont Type 248 oscilloscope and reading the voltage versus sweep length when "C" has been removed from the circuit. In the circuit constructed, these values were: $v = 150$ volts and $T = 5 \times 10^{-7}$ seconds. The current through the 6AG5 under these conditions was 10 milliamperes.

From the formula:

$$I = \frac{\Delta Q}{\Delta T} = C\,\frac{\Delta V}{\Delta T}$$

$$C = I\,\frac{\Delta T}{\Delta V} = \frac{10^{-2} \times 5 \times 10^{-7}}{150} = 33\ \mu\mu f$$

For a sweep of any desired length:

$$C + 33 \times 10^{-12} = \frac{\Delta T}{1.5 \times 10^{4}}$$

Any small error resulting from lack of accuracy in the above calculations or in commercial components is easily compensated for by adjusting the grid cathode potentiometer of the 6AG5 and changing the current through the 6AG5 enough to compensate for the error. This will compensate errors of up to 20% easily. The above calculations are based on a 200 volt push-pull sweep on the output of the phase splitter.

The fastest sweep obtainable with this circuit is, of course, that found above with "C" removed from the circuit and is about one half micro-second if reasonable care is used in constructing the circuit. This sweep is very linear as long as no attempt is made to get larger sweep voltages from it. Since timing markers are provided by the marker generator, the sweep is readily and accurately calibrated against its own markers. This should be done each time the value of "C" is changed, using the fine control provided.

Section 6

The Y-axis Amplifiers

The circuit details of the y-axis amplifiers are shown on Plate VII.

This section must meet the following requirements. It must delay the signal sufficiently to allow the sweep to start before the signal reaches the deflection plates. It must provide a voltage gain of about ten to one. It should have a reasonably flat gain characteristic up to about ten megacycles to make the one micro-second sweep useful. The output impedance of the final stage must be low enough to drive the capacity of the deflection plates of the oscilloscope. This is estimated to average about twenty micro-micro-farads. It should provide a push-pull output as this will give less distortion on some types of oscillograph tubes.

The delay line is designed to have a characteristic impedance of ten thousand ohms and is terminated in ten thousand ohms. It will have a time delay of one tenth micro-second per section. For these values L is one millihenry and C is ten micro-micro-farads, very convenient values. The number of sections required must be determined by trial and error after the entire circuit is constructed, but five to ten sections should be sufficient.

The amplifier consists of a phase splitter driving

6AG5's, which drive 807's. Plate loads are kept low to assure good high frequency response. The use of 807's is made necessary to obtain the output voltage required with such low values of plate resistance.

This circuit was not constructed but it should present few difficulties if care is taken to keep stray capacitances to a minimum in building it. If high frequency compensation is required, the component values are readily calculated from formulae given in "Radio Engineer's Handbook" by Terman.

Section 9

Conclusion

No attempt was made to design an overall power supply for the instrument, but the requirements of the power supplies have been worked out. If the complete equipment were built, these supplies should be built on a separate chassis and led into the instrument chassis through a multiple conductor cable. The following would be required:

D.C. Supplies, regulated:

250 volts at 250 ma.
150 " " 150 ma.
-90 " " 30 ma.

D.C. Supplies, unregulated:

500 volts at 50 ma.
400 " " 200 ma.
-400 " " 50 ma.

A.C. Supplies

6.3 volts at 20 amps.

Battery Supply:

6 volts at 1 amp.

Of the circuits previously discussed, all were actually constructed and tested as far as the laboratory equipment available would allow, with the exception of the Synchronising Amplifier and Power Amplifier circuits. As noted before, these are both relatively standard circuits whose construction should cause little difficulty. It is regretted that insufficient time was available to construct and thoroughly test the complete circuit.

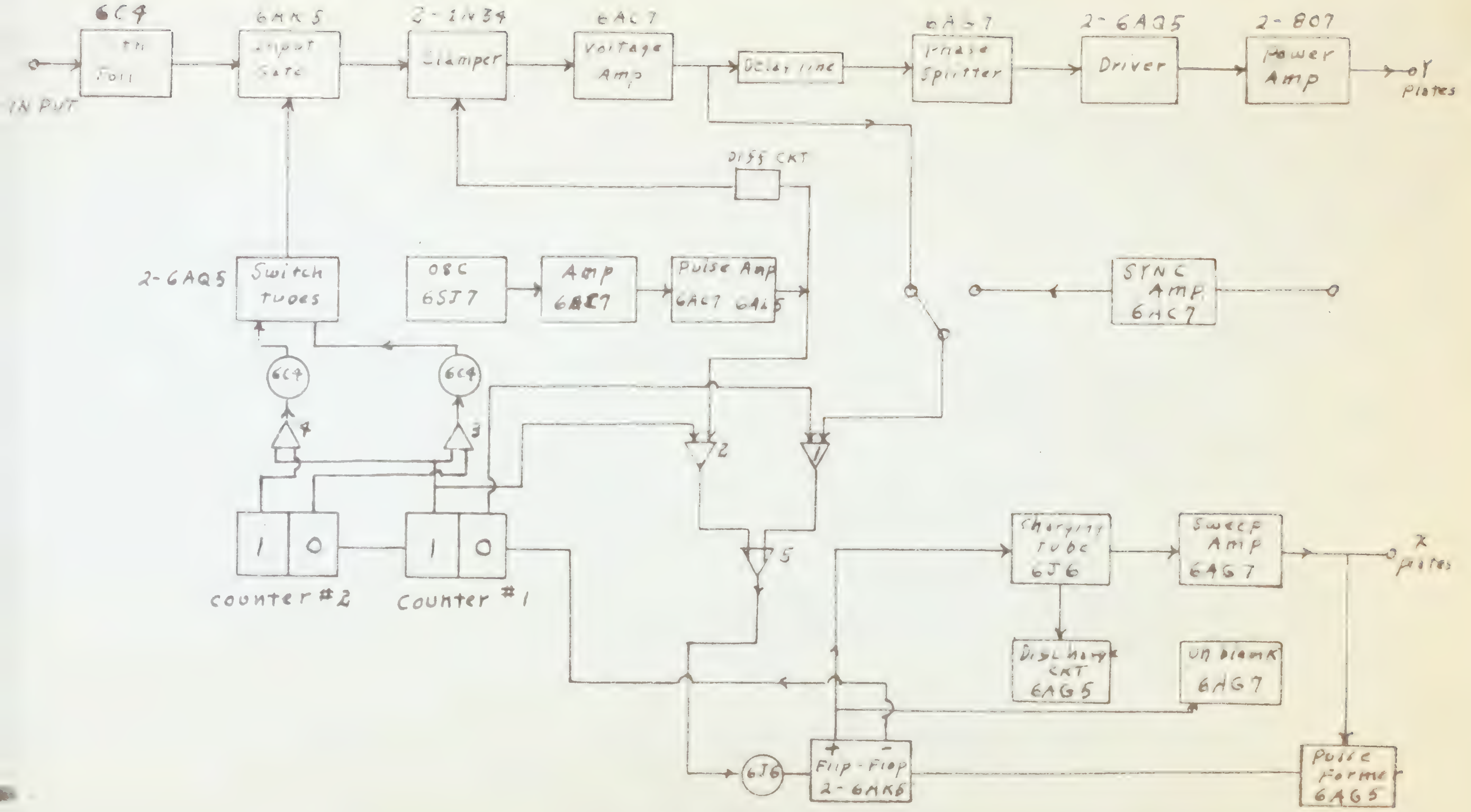


Plate I

OVERALL BLOCK DIAGRAM

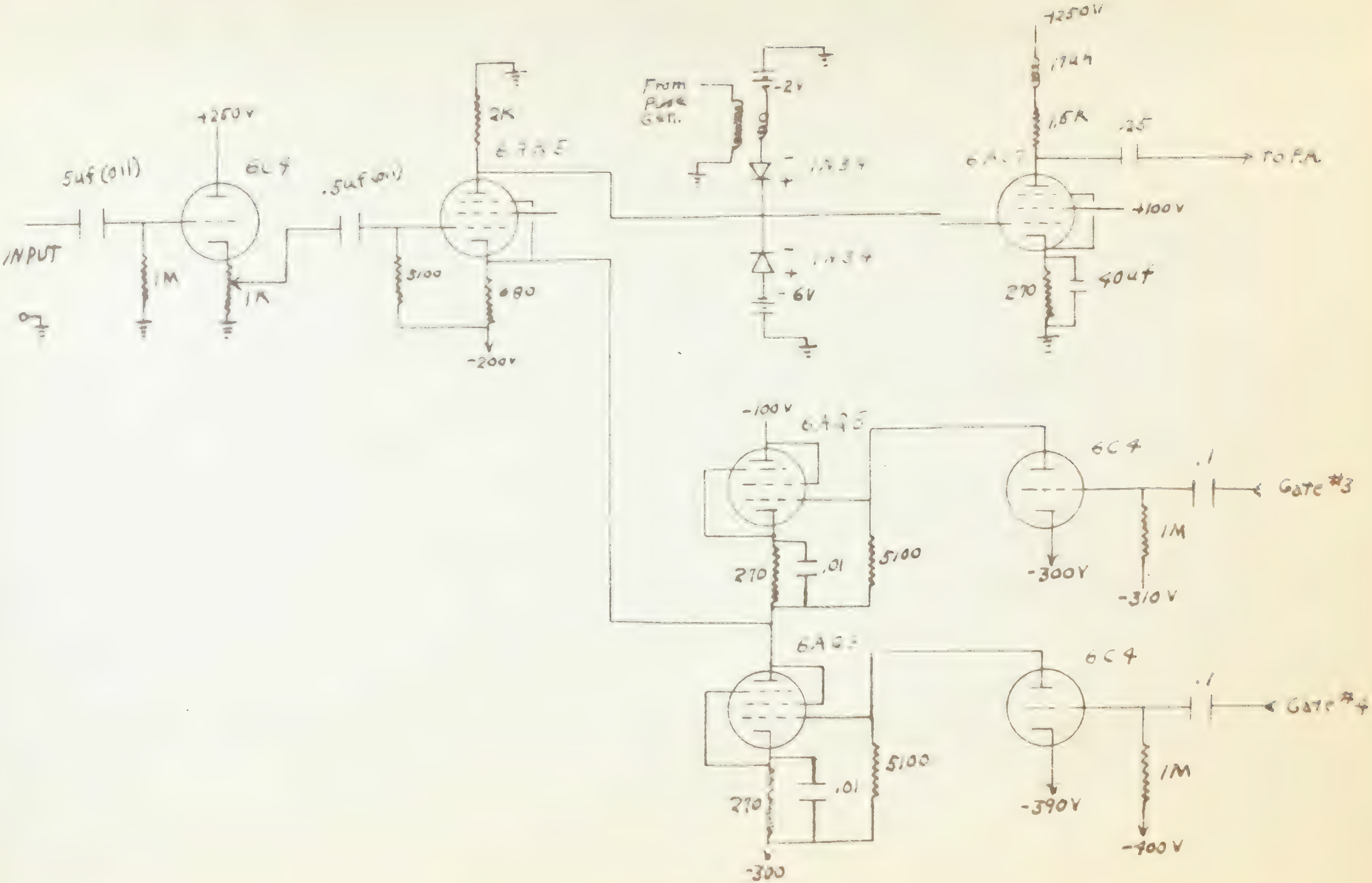


PLATE II
INPUT CIRCUIT

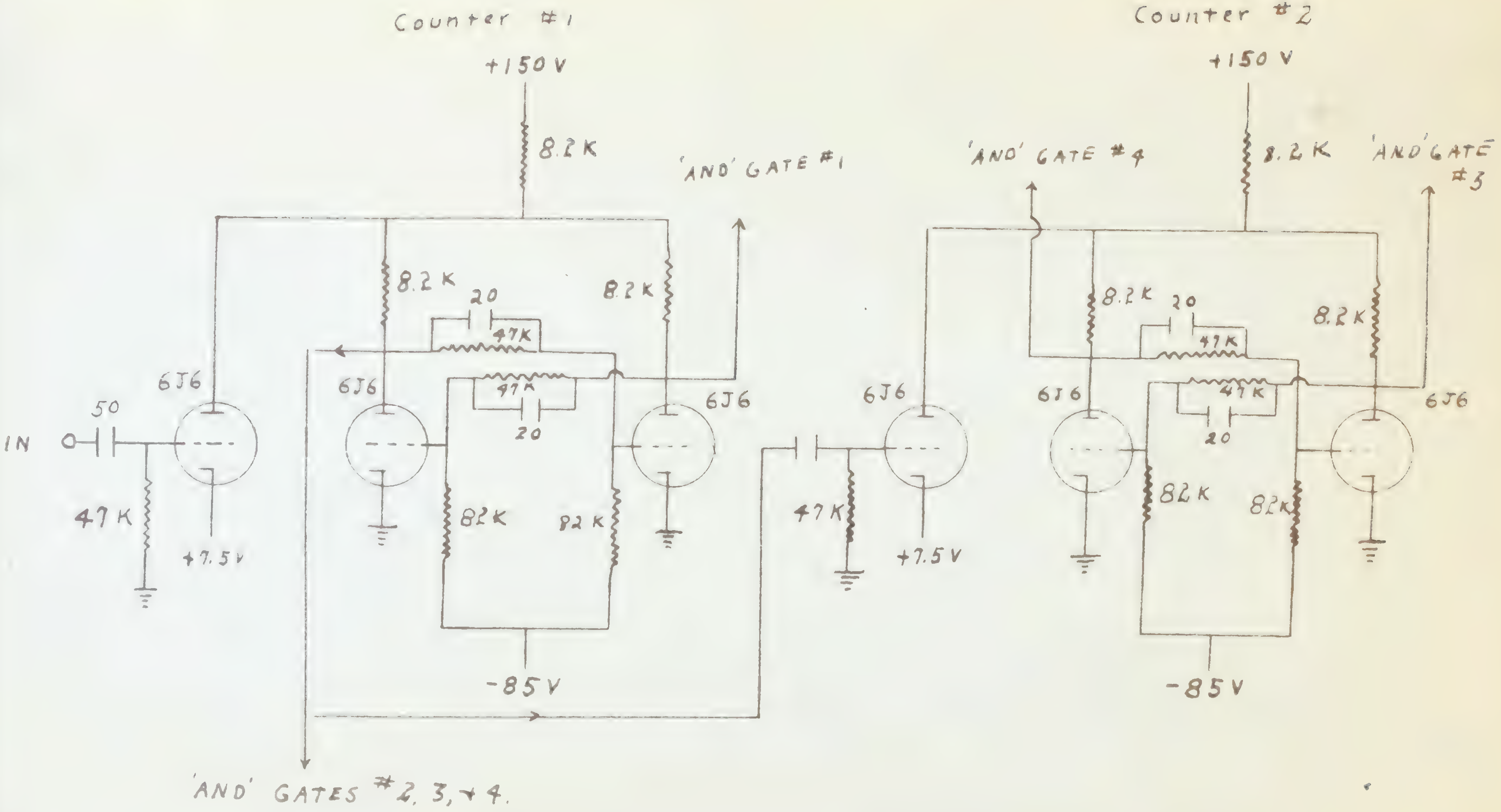


PLATE III (a)

Binary Counters

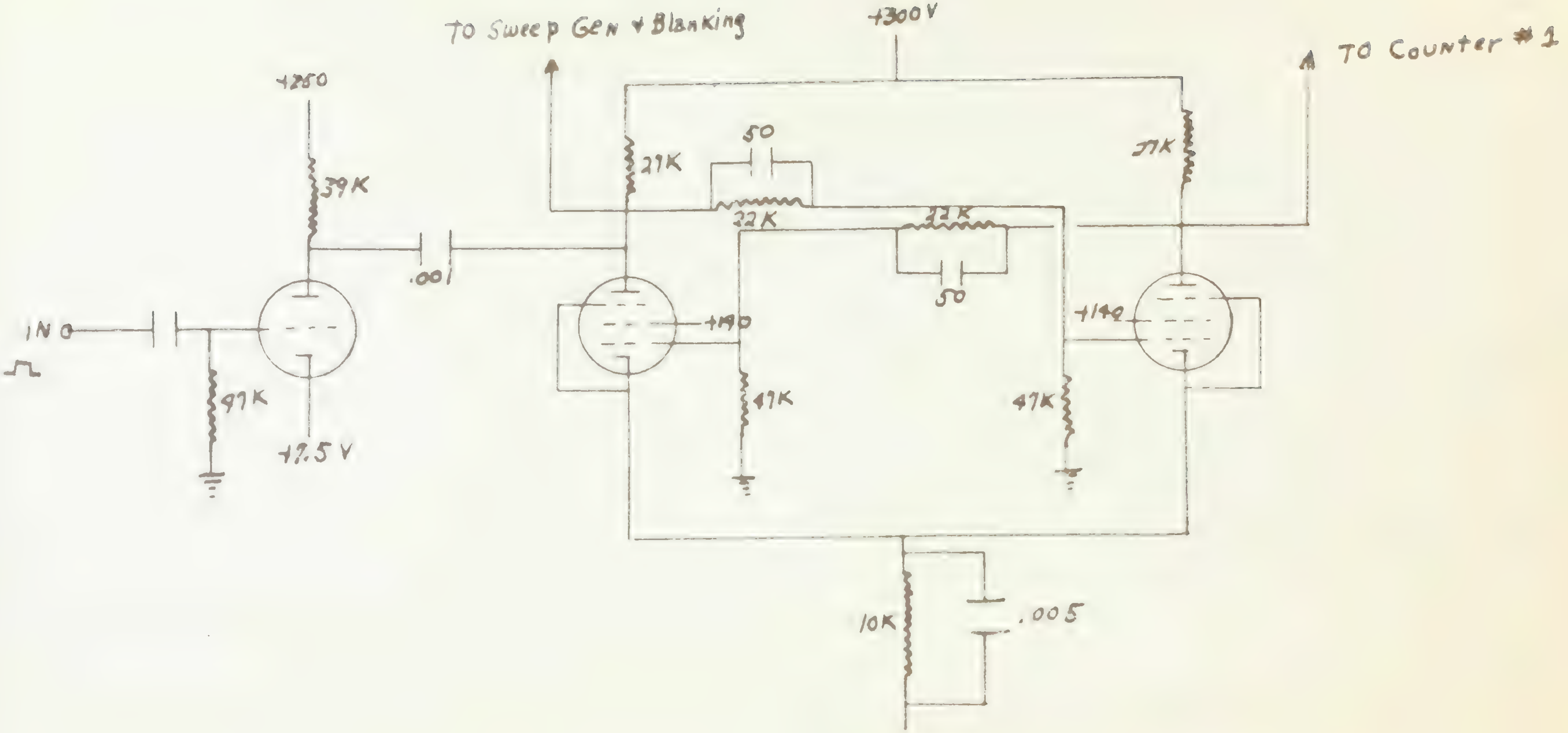
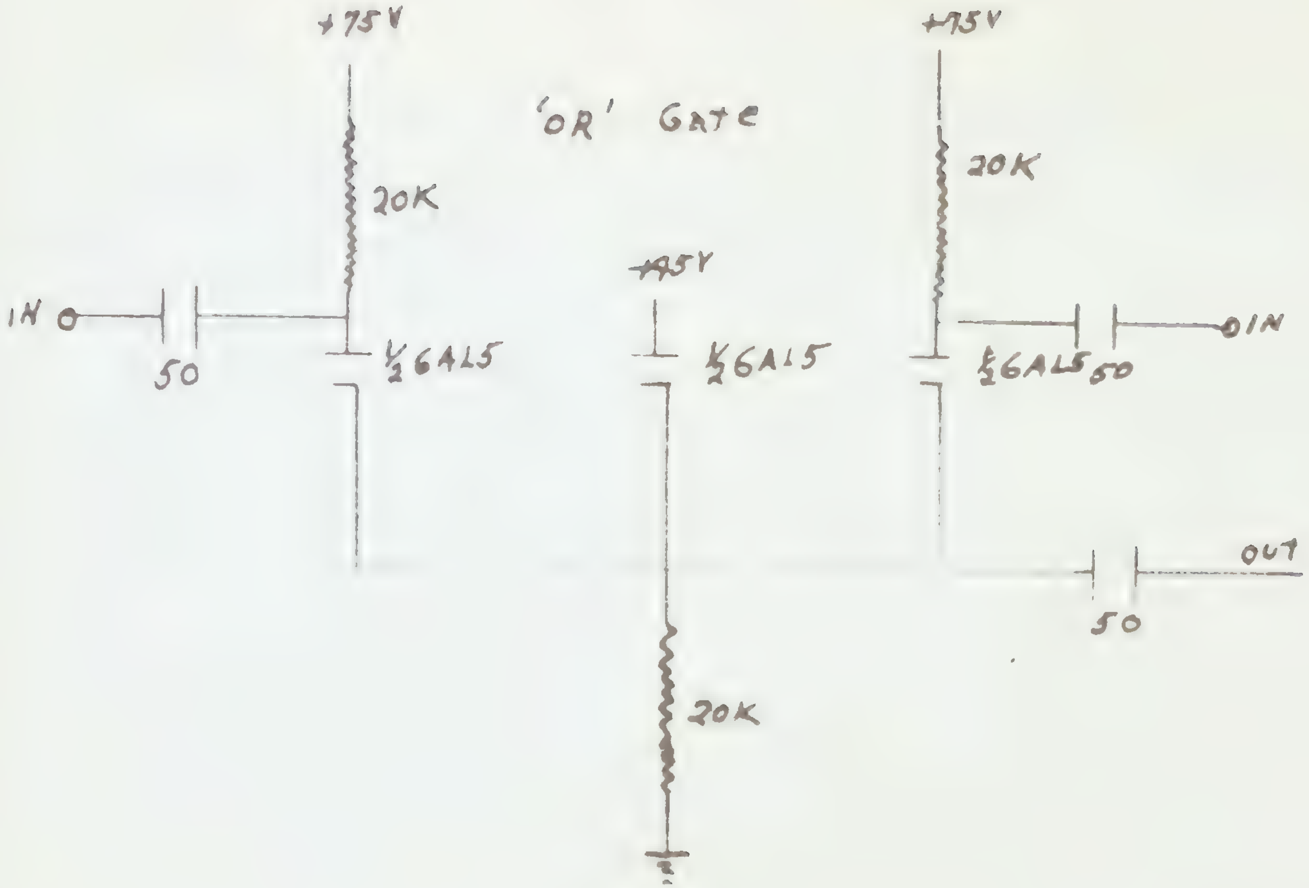


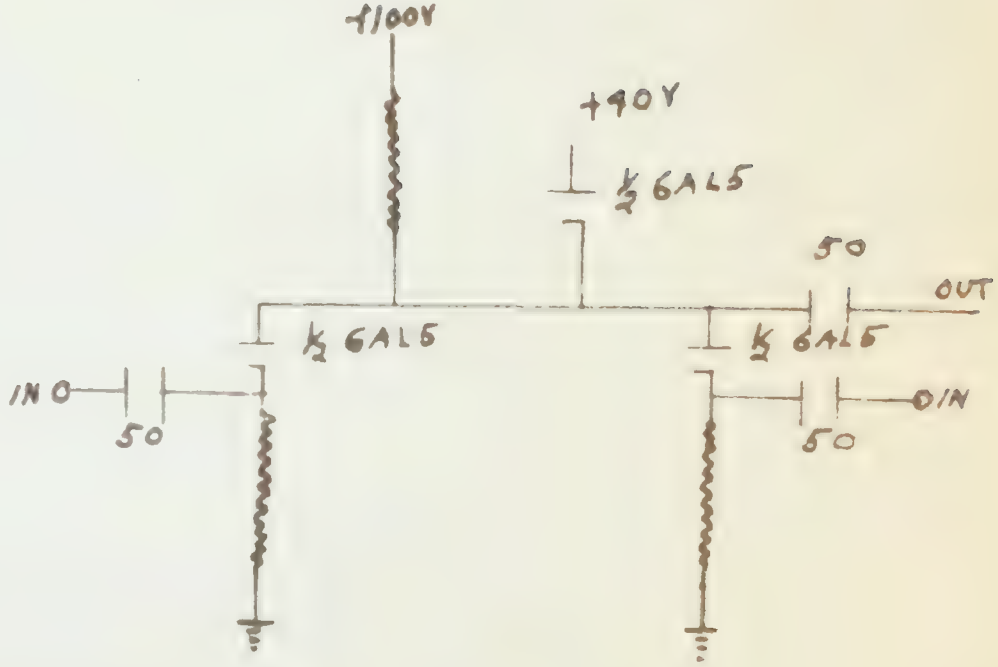
Plate III (b)

Flip Flop

'OR' Gate



'AND' Gate



All Capacities in uuf.

PLATE III (c)

Plate IV

The Marker Circuits.

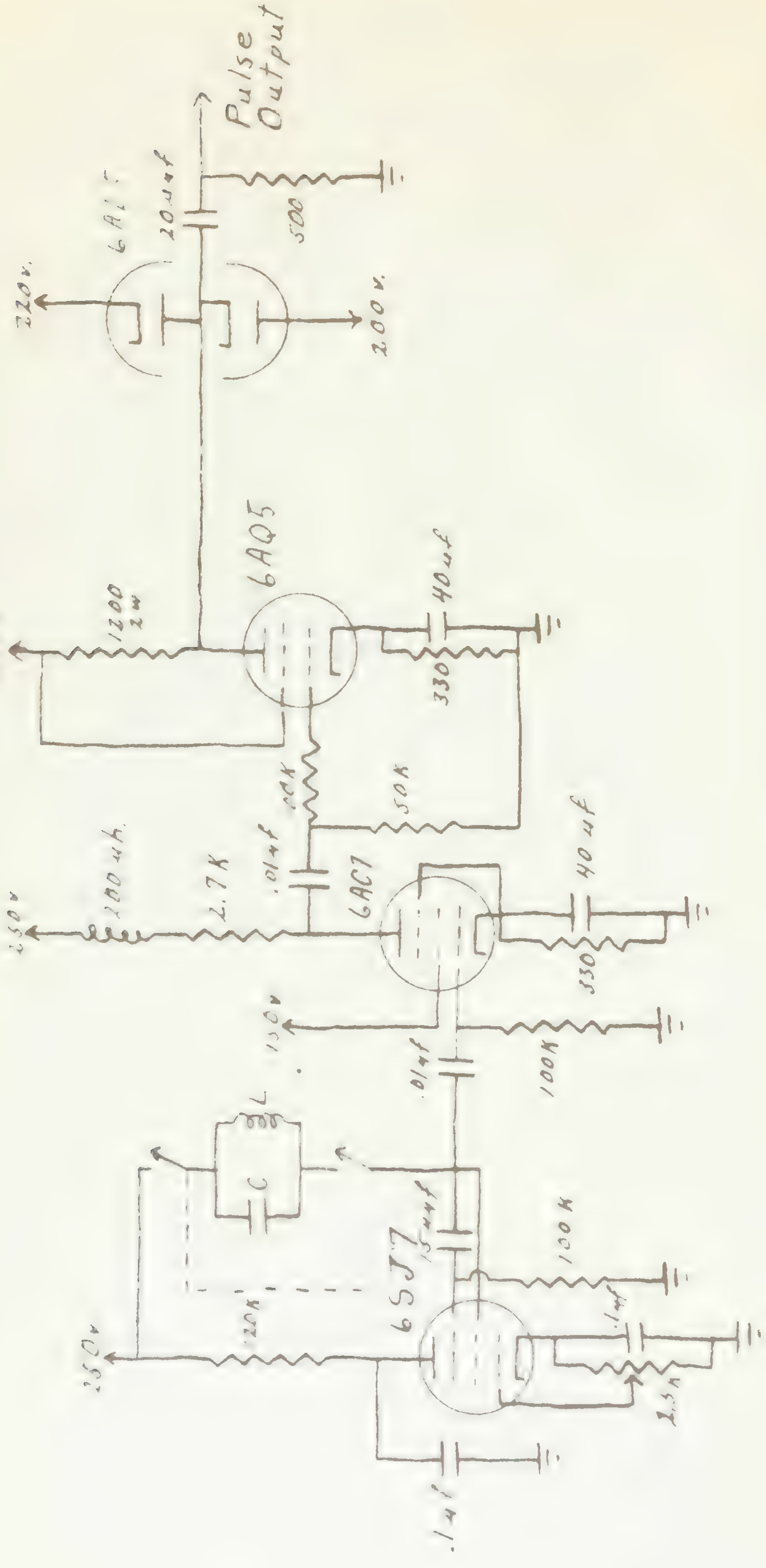
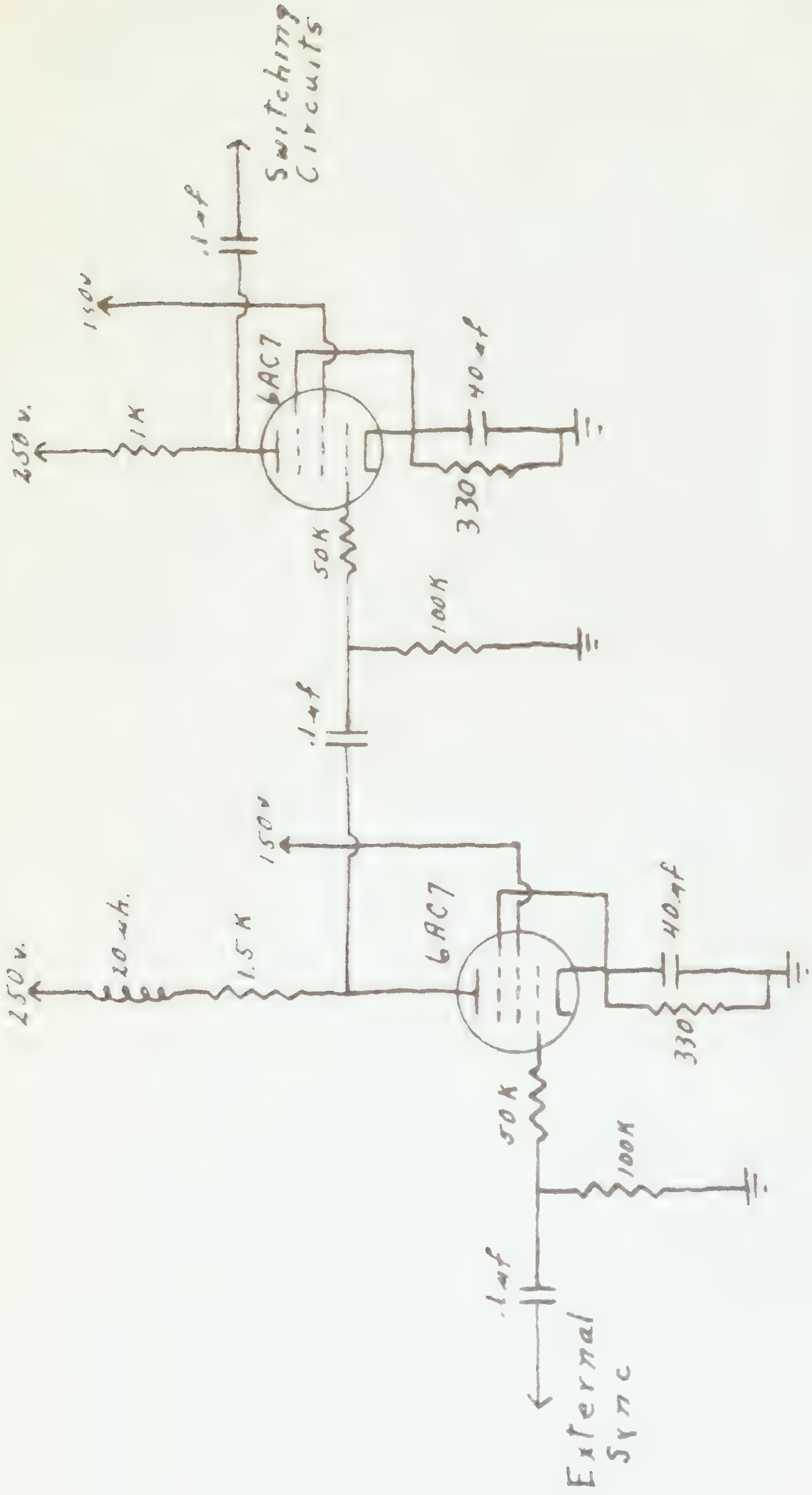


Plate V

The External Sync Circuit



The Sweep Generator

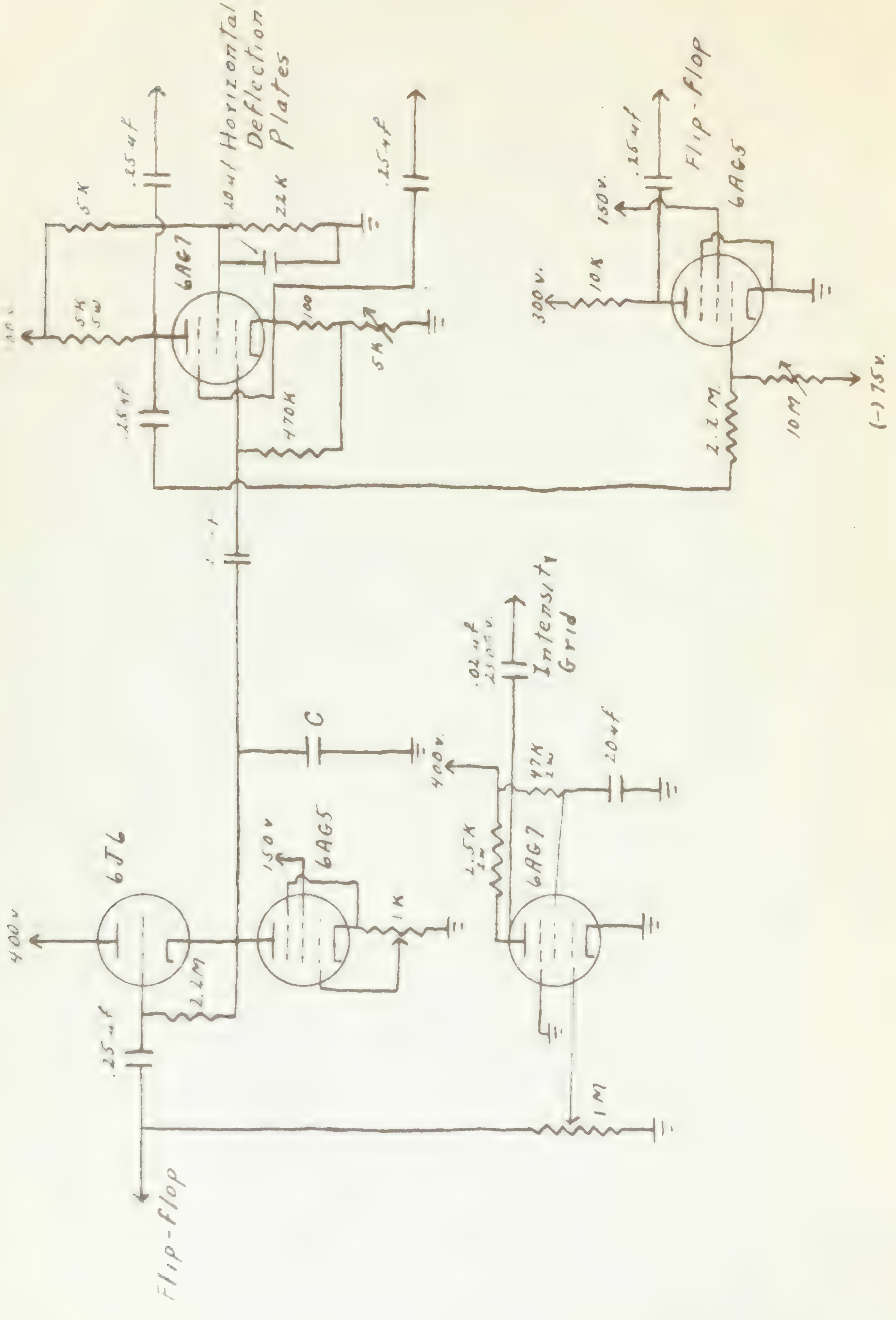
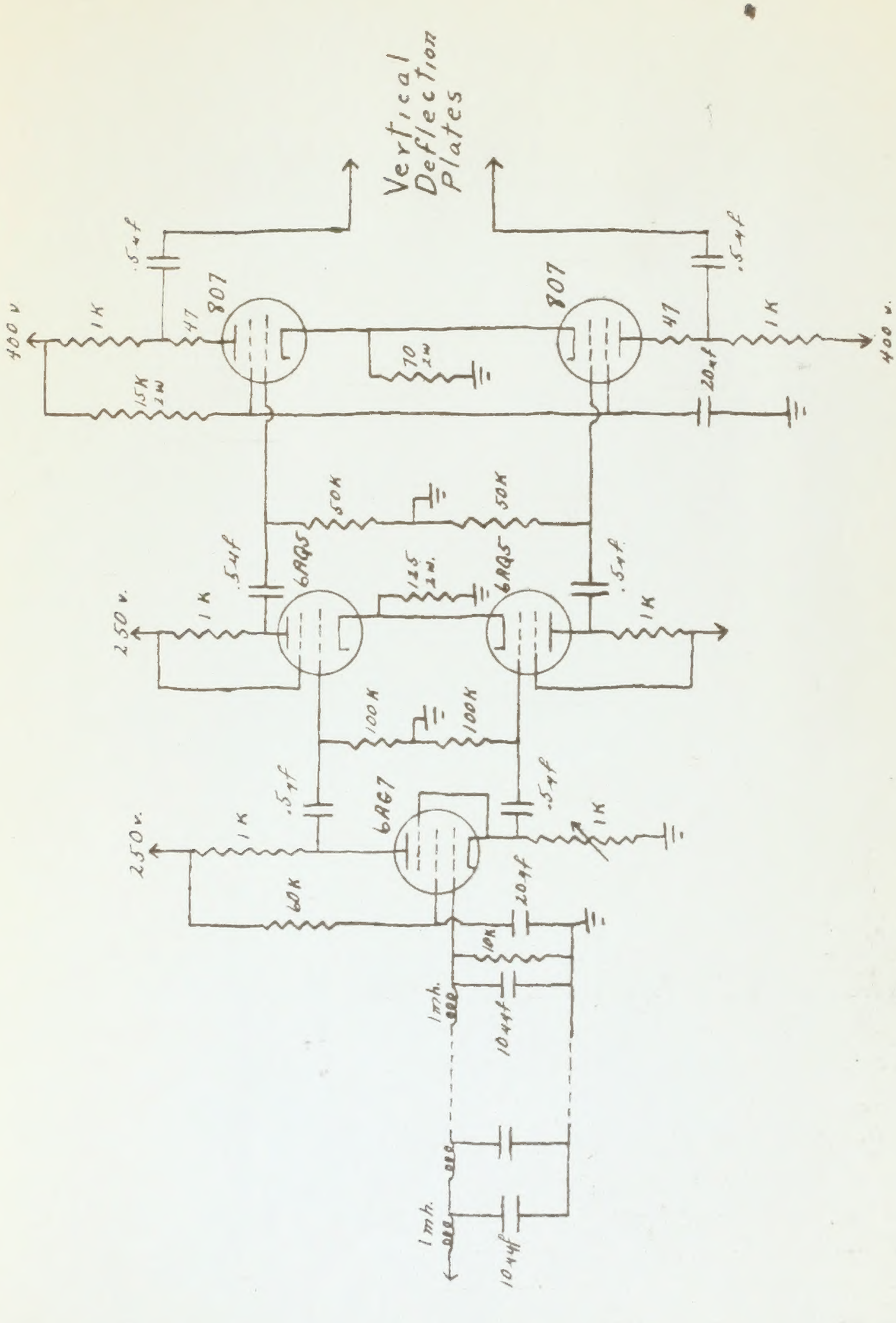


Plate VII

The Y-axis Amplifiers.



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